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A Strategy for Studies of the Marine Environment of Westernport Bay

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ABSTRACT: Certain aspects of man's effect on marine and estuarine systems, for example the influence of discharges on the dissolved oxygen regime, have been under study for many years. However, more recent investigations have a broad-ranging approach, consisting of sets of studies covering topics from the physical aspects of tide and current movements through to the structure of biological communities. The Westernport Bay Environmental Study is of the latter type.

Westernport Bay has extensive mudflats which are substantially covered by the seagrass, *Zostera muelleri,* and large sections of the coastline are lined by mangrove thickets, *Avicennia marina,* backed by saltmarsh swamps. Somewhat similar marine ecosystems have been investigated overseas. The intertidal grass, *Spartina alterniflora* and the mangrove *Rhizophora mangle,* growing in southern United States, have been shown to be a source of vegetable detritus. This can be swept to nearshore areas, or detritus consumers such as crabs, snails, mussels etc. can form the basis of a food chain extending to nearshore areas. In this way higher carnivores such as birds and commercial and recreational fish may be dependent on marine plant communities.

The quality of water has a decisive influence on the maintainence of the marine resources of the Bay. As stated, plant production may be important in the Bay ecosystem. On the other hand excessive water-borne nutrients such as nitrogen and phosphorus compounds may stimulate too much growth and eutrophic conditions will then occur. In some other marine areas this condition has caused large drifts of dead grass on beaches and the reduction of dissolved oxygen in the water. Toxic substances in marine areas can eliminate or reduce some species, or can accumulate in food chains so that the higher carnivores may contain deleterious concentrations.

The Westernport Bay Environmental Study consists of an integrated set of investigations both in the laboratory and in the field. This information will be used as a guide for environmental management.

INTRODUCTION

Intensive scientific studies of geographically limited parts of the marine environment involving teams of researchers are not new. Among the first was the British Natural History Museum Expedition to the Great Barrier Reef, 1928–9. Under the leadership of C. M. Yonge the Expedition spent a year at Low Isles, thirteen km off Port Douglas towards the northern end of the Reef. The Isles are isolated from any large population centre and consist of a sand cay and a mangrove-covered islet surrounded by a coral reef system. Physiological and growth studies were carried out in addition to an extensive ecological survey (Whitley 1932, Yonge 1940). Many other expeditions to a wide variety of marine areas and sponsored by many different organizations were to follow. These studies usually consisted of teams of scientists working in small groups or as individuals. The overall objective was to discover scientific principles and to unravel the detailed mechanisms operating in the marine environment.

Other types of studies of the marine or estuarine environment had also been developing. In 1885 regular examinations of the dissolved oxygen content of Thames River water were instituted; these have continued to the present day. The objective of the earlier work was limited to ascertaining the aesthetic condition and drinking quality of Thames River water and advising on how to improve or maintain river water quality (Anon. 1964).

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In recent years the problems of pollution and conservation have become acute in the near-shore marine environment in many parts of the world. It is adjacent to this zone that large urban, industrial and port complexes are located. Also recreational usage of the coastal marine environment has intensified. Many man-made environmental changes have occurred without any immediately apparent problems. But with the passage of time an interacting chain of environmental modifications has been observed, degrading both the natural environment and the human environment (see Fig. 1).

Management problems have arisen which, for solution, require a detailed knowledge of the marine environment (Butcher 1970). To supply this knowledge a new concept of marine studies has emerged, in which the scientific investigation techniques of various disciplines, and their results, are interwoven and integrated. This integration frequently opens completely new areas for investigation by offering new perspectives. The overall objective is not only to expand our knowledge of the natural marine environment but also to develop a broad understanding of man's interaction with the marine system.

ENVIRONMENTAL STUDIES IN MARINE SYSTEMS

The rapid expansion of the science of ecology has given an appreciation of the many interacting effects in natural systems. Most recent environmental studies have placed great emphasis on sets of broad ranging investigations covering those aspects of the physical, chemical and biological environment considered to be important. Good examples are the environmental studies of Port Valdez conducted by the Institute of Marine Sciences, University of Alaska, and the bio-environmental studies on the Columbia River estuary conducted by U.S.A. University and Government research teams. Both contain investigations ranging from physical characteristics through to chemical properties, nutrient cycling, primary production and interrelationships of invertebrate and vertebrate communities. It is noteworthy that in both cases the various investigations are directed primarily to understanding a single aspect of man's interaction with a marine system: at Port Valdez the effects of petroleum hydrocarbon pollution, on the Columbia River the effects of discharges of radioactive substances.

Although the aspect of man's interaction which

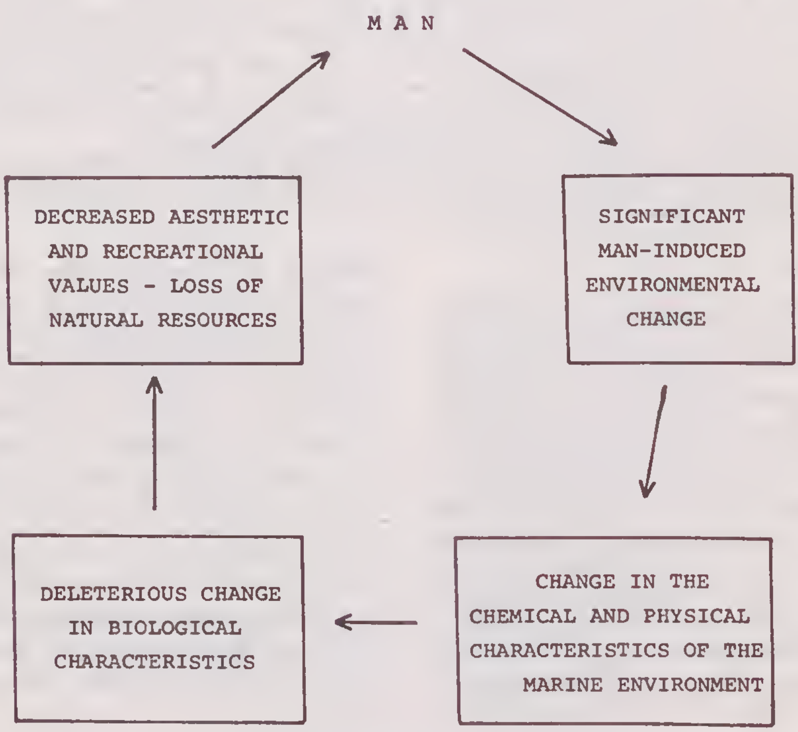

Fig. 1—Sequence of events often resulting from a significant environmental change.

is of interest may be limited, the investigations to arrive at some understanding of this may be many and diverse. Thus an environmental study of Westernport Bay would be expected to consist of an integrated set of research programs aimed at obtaining a comprehensive account of all relevant environmental interactions (Shapiro 1974).

Man's interaction with marine areas is usually highly complex, involving factors such as pollution loads of various kinds, shoreline reclamation, dredging, recreational pressures. An evaluation of such factors and their relative significance, now and in the future, is needed to define critical areas where information is required. Such an evaluation will involve an assessment of social values and requirements (see Fig. 1). The needs of people in the local area and perhaps aspects at a national or even international level will have to be taken into account. In many cases the impact of water pollution exceeds all others in importance. For example, extensive environmental studies have been carried out on the Thames River (Anon. 1964) and San Francisco Bay (Anon. 1972) to devise pollution control procedures.

Any environmental study of a marine area implies an interest in the environmental quality of that area over a period of time. In some cases improvement will be aimed at, whereas in others there will be safeguards against deterioration. Thus quantitative evaluation of the existing physical, chemical and biological status of an area will often constitute part of a study research program as a baseline for future comparisons.

Environmental studies in marine areas also need to investigate beyond the areas of direct interaction between man and the marine environment to develop an understanding of the ecosystem as an integral whole. In this way a concept of the possible extension of effects into the ecosystem from the area directly influenced can be obtained.

To define the necessary research objectives the key elements in the ecosystem must be identified as clearly as possible. Often very limited information will be available, so identification may have to be based on information available on other similar areas. In some instances, as the results of research become available, the initial intuitive concepts may be shown to be incorrect and a new direction taken.

It is noteworthy that in some overseas areas scientific information is available from a considerable period of research and observations. For example, Cowles (1930) published the results of a seven year biological survey of Chesapeake Bay. This was preceded by detailed but less broad-ranging studies by others on plankton and fish. These investigations were multiplied with passing years and continue up to the present time. As mentioned previously, chemical examination of the Thames Estuary which commenced in 1885 has continued to the present day.

In broad terms the overall aim of the Westernport Bay Environmental Study is to develop a program for the maintenance of water quality and conservation of marine resources in the Bay.

However, a limited amount of scientific information was available on the Bay at the commencement of the Study, and specific research objectives were arrived at using the information available, together with that on similar areas described in the scientific literature.

THE WESTERNPORT BAY ECOSYSTEM

According to Pritchard (1967) an estuary is a semi-enclosed coastal body of water which has a free connection with the open sea and within which seawater is measurably diluted with freshwater derived from land drainage. Estuaries are usually influenced by strong tidal action.

Components of the Ecosystem

Westernport Bay has many of the characteristics of an estuarine system (see Fig. 2). It has a catchment area of *c.* 3,100 km^2 in which annual rainfall varies from 66 to 152 cm, but freshwater inputs, mainly along the northern coast, are comparatively small. Nevertheless, significant variations in salinity occur. For example, salinity in the extreme northern reaches of the Bay averaged 33·5 parts per thousand and 33·0 parts per thousand in the East Arm with values increasing to 35·4 parts per thousand at the Entrance during the period July 1973 to January 1974 (Harris et al. 1974) (see Fig. 2). The salinity of open oceanic waters is usually approximately 35·4 parts per thousand. Thus Westernport does not experience the wide fluctuations in salinity which occur in many estuaries. Substances containing nitrogen, phosphorus, silica and other compounds occur in the Bay waters and also the input stream waters. Proportions of these substances are contributed by agricultural and urban development. Water temperatures vary from approximately 10°C in winter to approximately 22°C in summer.

The tidal range is approximately 2·3 m and extensive mudflats are exposed so that in a total marine area of 680 km^2 there are 270 km^2 of intertidal mudflats (see Fig. 2). The mudflats are substantially covered with the seagrass *Zostera muelleri* and along a total shoreline length of 263 km there are 108 km lined with mangrove thickets backed by a salt marsh swamp. The mangrove thickets contain only one species, *Avicennia marina,* whereas in the salt marsh swamp complex floristic associations occur, often containing *Arthrocnemum arbusculum* and *Salicornia* sp. (Bridgewater 1974). Bird (1971) has found that the coastline is comparatively active, building up in some places, with erosion in others. Apparently the building of harbors, harvesting of mangroves and other activities have had an influence on coastal processes (Enright 1973). Preliminary results obtained by Canterford and Ducker (1974) indicate that *Ditylum brightwellii*, a diatom, is among the most important components of the Bay phytoplankton community. Zooplankton constitute an important segment of the total planktonic population.

Faunal communities, including molluscs, annelids, arthropods and echinoderms, are associated with the seagrass and mangrove communities (McNae 1966) and other littoral communities also contain a large number of invertebrate species (Smith 1971). The subtidal benthic communities

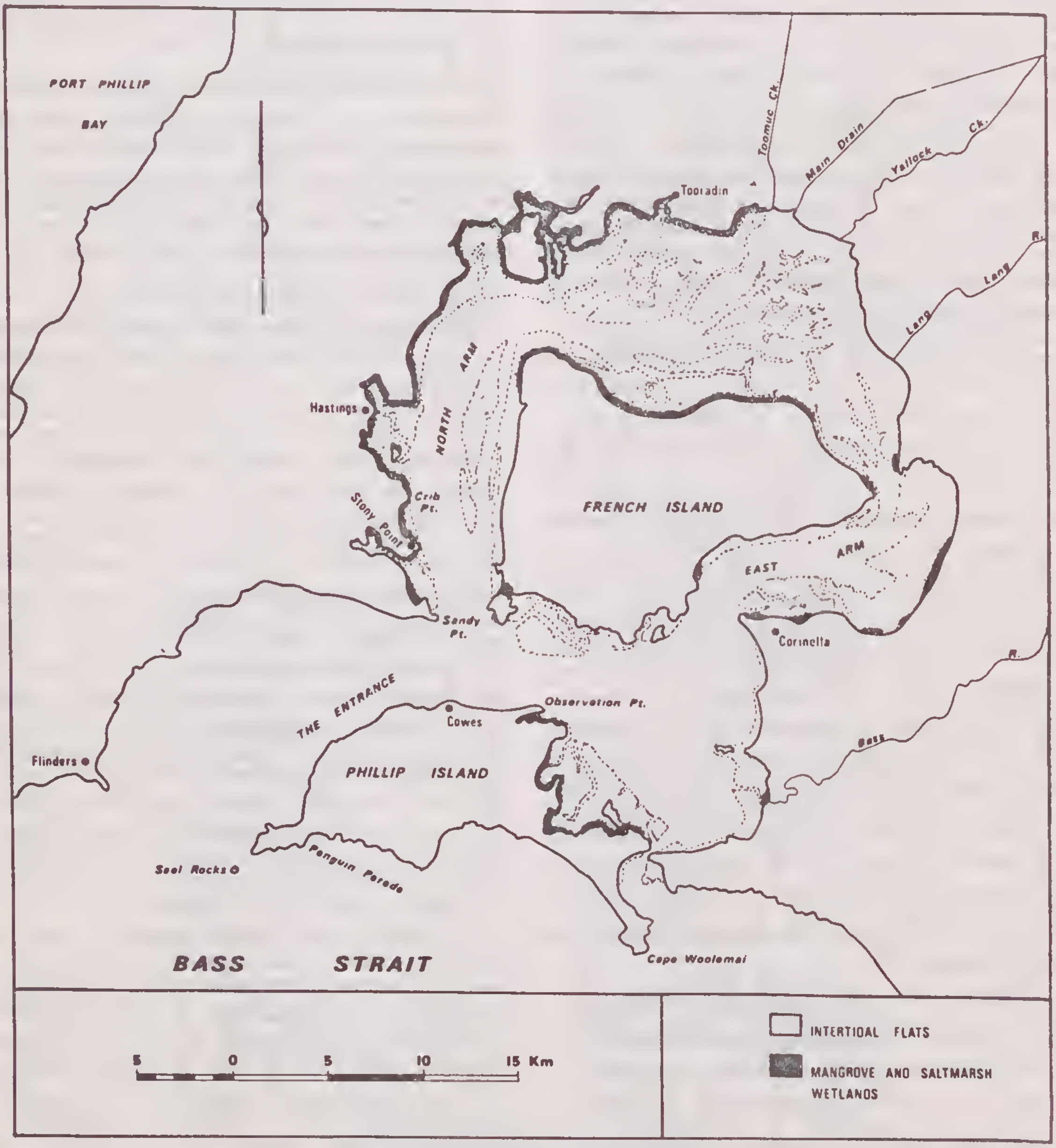

FIG. 2—Westernport Bay.

include numerous invertebrate fauna as well as the seagrass, *Heterozostera tasmanica* and the algae, *Caulerpa cactoides* (Watson 1971).

Gilmour (1965) has reported that the fish population of Westernport Bay includes some 35 species caught by professional fishermen. Of total Victorian landings of the fish King George whiting (*Sillaginodes punctatus*), 25% are made in Westernport Bay. During summer amateur fishermen are believed to harvest an equivalent amount to the professional fishermen (Gilmour 1965). However, many species are present which do not play a role in the fisheries. For example, the Smooth Toado, *Sphaeroides glaber*, occurs in substantial numbers.

Westernport Bay has a rich avifauna and the Bird Observers Club has listed the occurrence there of 271 species (Anon. 1969). Large colonies of the Short-tailed Shearwater, *Puffinus tenuirostris* (Norman & Gottsch 1969) and the Fairy Penguin, *Eudyptula minor*, breed on Phillip Island (Reilly & Balmford 1969, 1971). In addition, two cormorant species, the pelican, *Pelecanus conspicillatus*, the Black Swan, *Cygnus atratus*, and a number of other species breed in Westernport Bay (Loyn 1974). The mudflats form a rich feeding area. Black swans are said to feed on the rhizomes of the seagrasses.

The large seal colony (*Arctocephalus tasmanicus*) at the entrance to the Bay which has been described by Warnecke (1968), and the Fairy Penguin colony, are major tourist attractions.

Above are outlined what are to the best of our knowledge some of the many elements in the Westernport Bay ecosystem.

Interactions within the Ecosystem

As a general rule, estuaries and inshore marine areas are among the most productive environments on earth (see Table 1). Salinity and temperature are much more variable than in the oceanic environment but food conditions are much better. Odum (1971) attributes this greater production to a number of factors. Perhaps the most important of these are the promotion of nutrient circulation by tidal action and the availability of a variety of habitats for primary producers. Thus phytoplankton, benthic microflora and large attached plants can co-exist. However, Ragotzkie and Pomeroy (1957) have found that light penetration is low in the turbid waters of many estuaries and so phytoplankton production is often low.

Teal (1962) conducted detailed studies of energy flows in a Georgia salt marsh. He found the major primary producers were the grass, *Spartina alterniflora*, and algae in the intertidal zone and these producers were linked into an

Table 1

Primary Production in Various Ecosystems*

Ecosystem	Primary Production (kilocalories x $10^3/m^2/day$)
deserts	< 0·5
grasslands deep lakes forest some agriculture	0·5 — 3·0
moist forests shallow lakes moist grasslands moist agriculture	3 — 10
some estuaries coral reefs intensive year-round agriculture	10 — 25
continental shelf and deep oceans	0·5 — 3·0

* From Odum (1971).

energy flow system as indicated in Fig. 3. The key links between primary production and energy flow into consumer food chains are the algal-detritus feeders listed under herbivores in Fig. 3. Teal found that the quantities of energy involved in this system were as indicated in Fig. 4. The tides are of critical importance in this environment since the water flows permit the export of production into nearshore areas. In this case up to 45% of the net primary production from the salt marsh is available for export. This energy source is of considerable importance in maintaining nearshore fisheries. Similar results were obtained by Odum and de la Cruz (1967) in investigations of the same ecosystem.

In more recent years Jefferies (1972) has used chemical techniques to investigate the carbon flow through food chains associated with the *Spartina* in salt marsh systems. This has been done by examining the fatty acid composition of the various biological components. *Spartina* contains a distinctive pattern of fatty acids which has been traced through various parts of the ecosystem to fish in the nearshore environment.

Heald and Odum (1970) and Odum (1971) have conducted a number of investigations of the ecosystem based on the Red Mangrove (*Rhizophora mangle*) in southern Florida. By gut analysis and other techniques the operation of the ecosystem was pieced together. This is shown in generalized terms in Fig. 5. Thus an ecosystem is in operation in which primary production is provided by mangrove leaves falling into the shallow waters yielding detritus, and the detritus consumers provide the link between primary pro-

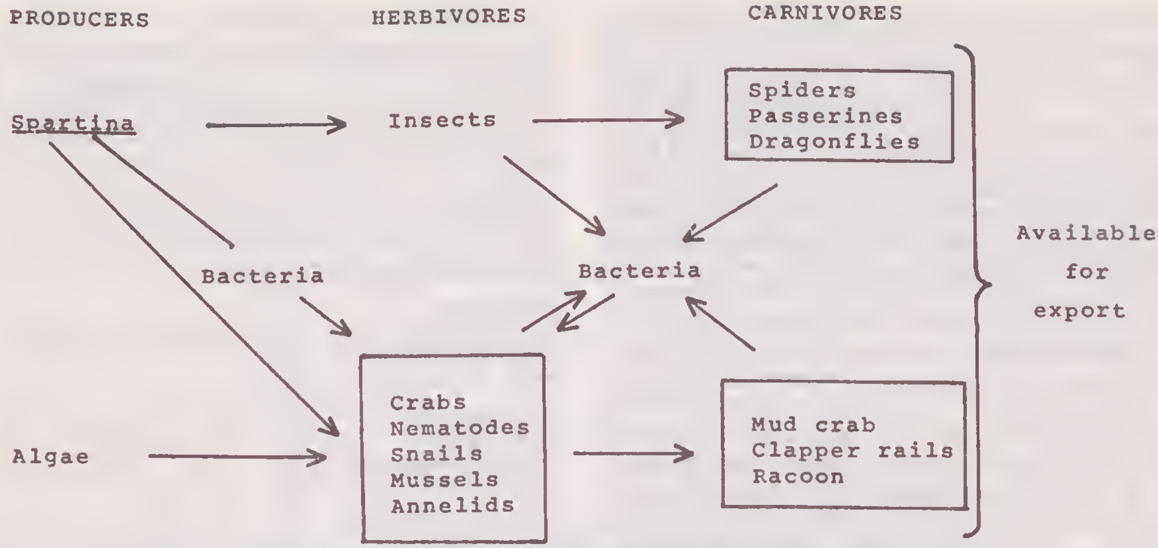

FIG. 3—Energy flow pathways in a Georgia saltmarsh (after Teal, 1962).

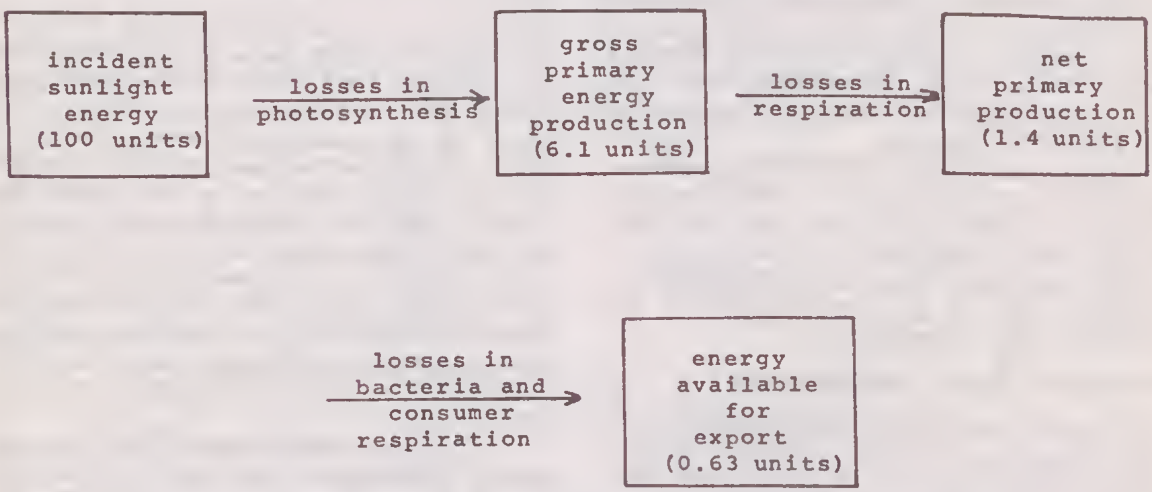

FIG. 4—Quantities of energy flowing through a Georgia saltmash (after Teal, 1962).

duction and consumer food chains. In this manner birds and game fish are dependent on the primary production from the mangrove communities.

Walsh (1967) unravelled a complex food web based on detritus from several mangrove species and phytoplankton. The web comprised a large number of species at several trophic levels. The detritus and algae consumers included polychaetes, nematodes, zooplankton, and the top carnivores were a number of large fish species.

The Knysna Estuary in South Africa has, in general terms, many similarities to Westernport Bay. It has extensive *Zostera* and *Halophila* beds in the intertidal areas which are fringed with salt marsh. A thorough investigation of the ecology of the estuary has been carried out by Day (1967). Attached plants (*Zostera* and *Halophila*) and phytoplankton initiated a food web terminating in and including several important food and game fish such as the Kob (*Johnius hololepidotus*), the Garrick (*Lithognathus lithognathus*) and the Sea Mullet (*Mugil cephalus*).

The Westernport Bay ecosystem bears many similarities to the systems described. It contains an extensive area of fringing mangroves and salt marsh swamps and also a substantial proportion of the Bay littoral is covered by seagrasses. Thus in general terms it could be suggested that the Westernport ecosystem will be based substantially on mangrove and seagrass primary production, and a detritus consumer link into the Bay food web. Perhaps a generalized ecosystem similar to that diagrammatically represented in Fig. 6 is in operation. Although this may describe the major pathways of carbon and energy there are some exceptions. For example, Black Swans (*Cygnus atratus*) are known to feed directly on seagrass by consuming the under-surface rhizomes, while seals, large fish and some birds may derive their food only partially from Westernport Bay.

The mangroves and seagrasses have ecological influences additional to those described above. The mangroves are believed to provide roosting areas for birds and, together with the seagrasses, shelter and protection for fish, particularly juveniles. In addition, mangroves have been found to stabilize the shoreline and in Westernport Bay have been an agent of land building (Bird 1971).

INTERACTIONS OF MAN

Human activities can have a significant impact on marine ecosystems. This can be due to direct removal of biological elements in the system or to the indirect effects of environmental modification.

Elimination of Elements in the Ecosystem

In 1798 when George Bass discovered Westernport Bay he noted the large seal colony at Seal Rocks and also colonies elsewhere in Bass Strait. Warnecke (1968) has reported that seven months later the first sealing vessel *Nautilus* left Sydney for Bass Strait, to return with 5,000 skins and several tons of oil. Later, sealers were attracted from all over the world, and in 1860 it is reported that only 100 seals remained at Seal Rocks

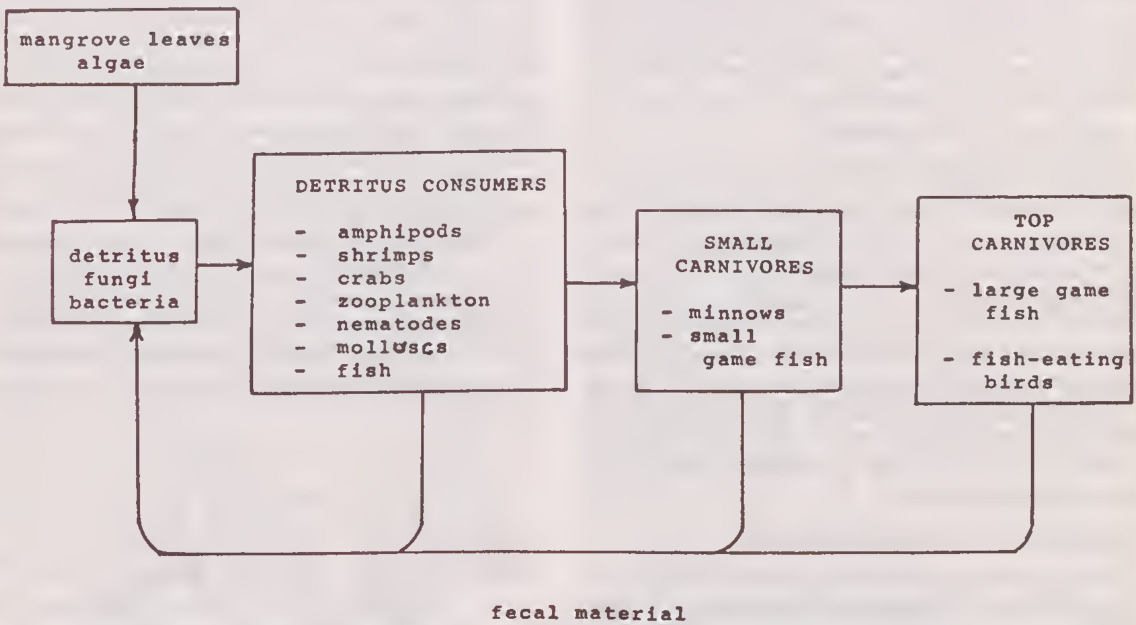

Fig. 5—Food chain in estuarine waters in southern Florida based on mangrove detritus (adapted Odum, 1971).

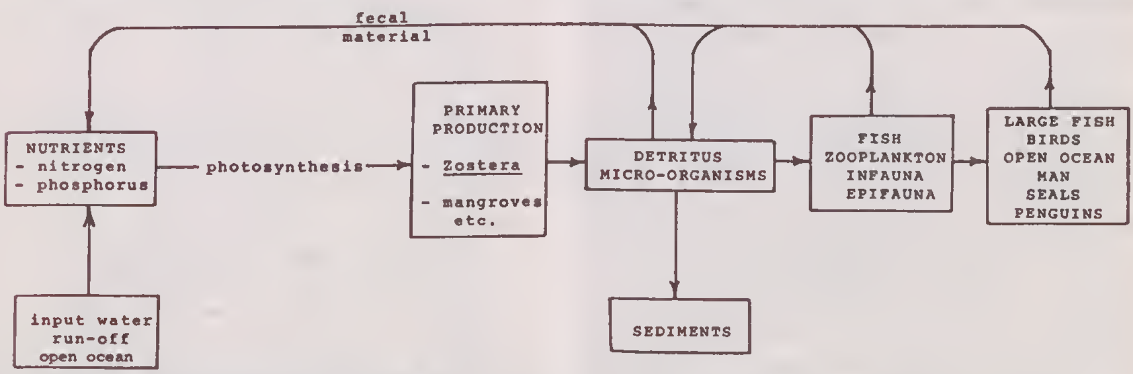

Fig. 6—A possible generalized energy flow pattern for the marine ecosystem of Westernport Bay.

(Warnecke 1968). This was the first noteworthy impact that western man made on the marine environment of Westernport Bay. Since that time, however, the seal colony has recovered and is now protected by legislation.

There is little doubt that subsequent settlement, for example the draining of the Koo-wee-rup Swamp, decreased the habitat available for aquatic birds, and the numbers of some of these have most likely decreased. Habitat was probably affected also by the harvesting of mangroves in parts of the Bay for use in barilla soap manufacture.

Another interesting effect on the marine environment concerns the Mud Oyster (*Ostrea angasi*). In 1860 ten oyster leases were operated in various parts of the Bay, from east of Observation Point, Phillip Island to north of French Island (Anon. 1860). By the early 1900's the industry had ceased to be profitable due to lack of oysters. Today oysters do not seem to be common and the reasons for their apparent failure to re-establish in large number are obscure.

Fishing, hunting, dredging of channels, construction of harbors and many other activities have all led to the elimination of biota but the overall impact on the ecosystem is not known. Apart from the general concept as previously outlined, our knowledge of the detailed community structure and inter-relationships of Westernport Bay biota is primitive. However, if the general scheme described diagrammatically in Fig. 6 approaches the operation of the Bay ecosystem in reality, conservation of the primary producing systems may be required to maintain the aquatic resources of the Bay.

Modification of the Environment

The impact of environmental modification on the structure of biological communities is very complex. Some concept of the interactions involved can be obtained by considering the inter-relationships described by McErlean and Kirby (1972) in a small food web consisting of ten components (see Fig. 7A). Each horizontal set in the diagram indicates a different trophic level. Thus each component derives its food from those below it and the arrows indicate the specific feeding patterns. If the community is placed under stress, segments of the food web may be eliminated. Such stress could occur due to removal of habitat, pollution or over-fishing. If species Nos. 4, 6 and 7 were eliminated the food web would adopt the modified form shown in Fig. 7B. Thus, the pattern of energy flow in the system would be quite different from its original form. Species No. 5 will be placed under the full feeding pressure of Species Nos. 8 and 9, rather than as one alternative food source amongst three species. The production of this species may not have the capacity to adjust to the new circumstances and so the energy flow in the whole system may be reduced.

It can be seen from this example that the larger the number of species in an ecosystem the larger the number of food pathways. Thus there are numbers of alternative food sources available if some species are eliminated. Therefore, it could be expected that generally ecosystems of high diversity will have a greater capacity to absorb environmental stresses than simple systems.

The waters of the Bay directly affect the life processes of all the plants and animals of the Bay ecosystem. Water-borne toxic agents may affect the ecosystem and operation of food chains in the manner previously described. But some toxic materials, although they may occur in sub-lethal or even trace concentrations, are biocumulative and may exhibit abnormally high concentrations in individual animals, and magnification through food chains. This effect has been well demonstrated with pesticides, heavy metals and certain radioactive substances (Connell 1974a).

Thus, if the ecosystem operates as illustrated in Fig. 6, those biota highest in the food chain would be expected to contain the highest concentrations of any biocumulants present. The hydrocarbons form a slightly different class of biocumulants. Although these substances accumulate in the fatty

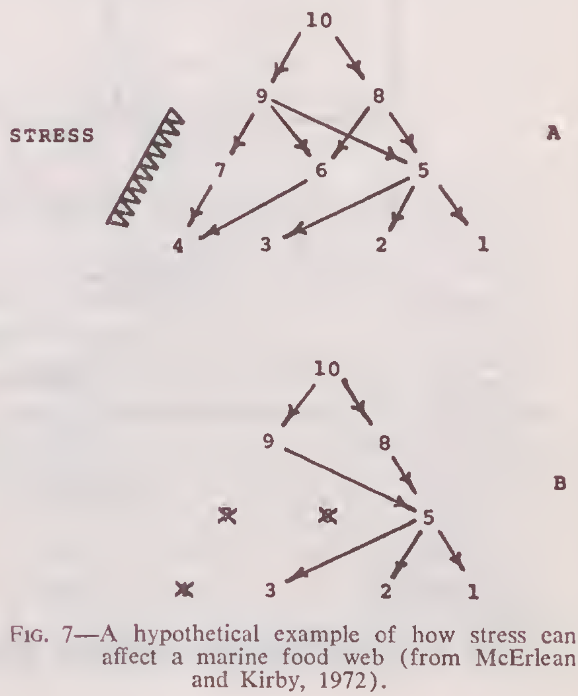

Fig. 7—A hypothetical example of how stress can affect a marine food web (from McErlean and Kirby, 1972).

tissues of marine animals there has not yet been a convincing demonstration of magnification in food chains. The effects of hydrocarbons on marine animals are obscure, but trace hydrocarbons have caused tainting in the flesh. In some cases this has caused extensive damage to important fisheries (Connell 1974b).

Previously, the possible importance of plant production to the maintenance of the Bay ecosystem was mentioned. On the other hand excessive concentrations of nutrient substances in marine waters may result in over-production by the various plant communities and the development of eutrophic conditions. In marine areas where this condition has developed, large quantities of plant detritus are produced which the detritus consumers cannot assimilate. Often the detritus stimulates bacterial activity and removal of dissolved oxygen from the water occurs, giving anaerobic conditions. Under these conditions large drifts of dead seagrass on beaches could be expected, as well as water areas where noxious gases, such as hydrogen sulphide, are generated. Thus the concentrations of nutrient substances in the Bay waters will have an optimum level at which the ecosystem is adequately maintained but eutrophic conditions do not develop.

In the Thames Estuary and many other estuaries, large quantities of organic wastes including sewage, food processing wastes, etc. have been discharged. The natural bacterial populations have multiplied and, in doing so, have consumed the dissolved oxygen in the water and anaerobic conditions have developed (Anon. 1964). These conditions occur in many Australian rivers where large discharges have been made (Connell 1974a). Such conditions could occur in Westernport Bay if large quantities of untreated organic wastes were permitted to enter the Bay waters.

STUDIES OF WESTERNPORT BAY

On the basis of the results obtained in other investigations on similar environments to Westernport Bay and on possible interactions of man with the ecosystem, a set of co-ordinated studies have been initiated. The tides and currents of the Bay are being measured as a basis for understanding the physical movement of substances. Also under investigation are the chemical characteristics of the waters and the manner in which nutrient substances, particularly nitrogen and phosphorus, are cycled between plants, detritus and water. Related to this are the investigations of primary productivity and the flow of carbon from primary production into the Bay ecosystem. As a basis for these investigations the seagrasses, mangroves and salt marsh are being mapped in detail.

The interactions of man with the Bay system are being examined in investigations of coastal dynamics, dredging, occurrence of biocumulants (such as heavy metals and pesticides) and also bioassay studies of the effects of toxic substances on Bay biota. To assess the current status of the Bay ecosystem and provide a baseline for assessment of any environmental changes, the populations of benthic animals, fish, zooplankton and birds are being evaluated.

CONDUCT OF MARINE ENVIRONMENTAL STUDIES

The multidisciplinary nature of environmental studies necessitates the use of personnel with disciplines ranging from the physical to biological sciences. In some cases such personnel are available within the one institution and the study is carried out as part of that institution's research program. This was so in the studies conducted on Port Valdez by the Institute of Marine Science (Hood et al. 1973), University of Alaska, and on San Francisco Bay by the University of California (Anon. 1966). In other cases a consortium of institutions may provide the range of expertise needed. The Chesapeake Research Consortium is an alliance between Johns Hopkins University, University of Maryland, Virginia Institute of Marine Science and the Smithsonian Institution. An environmental study of Chesapeake Bay was conducted by the Consortium which formed a Steering Committee and appointed a Principal Investigator (McErlean et al. 1972). The Principal Investigator co-ordinated the activities of almost forty research teams to arrive at a final result in approximately nine months. Some environmental studies have been carried out by private consultants. For example, Kaiser Engineers were contracted by the State of California to carry out studies on San Francisco Bay (Anon. 1972).

In environmental studies of the Columbia River, U.S.A. (Pruter & Alverson 1972), Waitemata Harbour, N.Z. (Anon. 1972–1973), Port Phillip Bay (Croxford et al. 1973) and a number of other marine areas, a combination of government employees, university personnel and private consultants were used. This would seem to be the most common method of conducting environmental studies: expertise is drawn on as appropriate.

In the Westernport Bay Environmental Study knowledge and expertise have been used where they can be obtained. The result has been a combined research team including government employees, university personnel and private consultants.

CONCLUSIONS

The array of investigations now in progress cover those aspects of the Bay ecosystem considered to be important. The results should provide a sound basis for environmental management of the area. Nevertheless, the complexity of the Bay ecosystem is immense. Chemical components in the water interact with biota, individually and as segments of an interdependent community. Superimposed on this are seasonal fluctuations due to changes in water temperatures, light intensity and water salinities caused by different water runoff behaviour.

The most suitable way in which the results of various investigations can be integrated to form a comprehensive scheme is by mathematical modelling assisted by computer techniques. Ecological modelling of the Westernport Bay system is now in progress. However, mathematical modelling of marine ecosystems is in its infancy and a great deal more progress is required before the technique can become an effective management tool.

Whatever management decisions are made concerning Westernport Bay, there will be a need for techniques to monitor the condition of the ecosystem. Many methods have been suggested involving Indicator Species, Bioassay Techniques, Chemical Evaluations etc. Probably the most satisfactory method to document environmental changes is by the determination of community structure. A variety of mathematical measures of community structure are available. They can be applied to any segment of the biota, and currently population data is being obtained on zooplankton, benthic invertebrates, fish, birds and macrofauna in seagrass communities. This method has a great advantage in requiring no extrapolations or assumptions to relate the results to the ecosystem. The results are a direct measure of the ecosystem itself, which is the prime concern of management.

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REFERENCES

ANON., 1860. Map of Westernport Bay showing oyster leases, Lands Department, Melbourne.

————, 1964. *Effects of Polluting Discharges on the Thames River—Water Pollution Research Technical Paper No. 11.* HMSO, London. 609 pp.

————, 1966. *A comprehensive study of San Francisco Bay.* Vols. 1-7, University of California, Berkeley.

————, 1969. The Westernport environment. *Victoria's Resources* 10: 14-17.

————, 1972. *A study of biostimulants in San Francisco Bay—Delta Waters.* Public. 44, California State Water Resources Council Board.

————, 1972-1973. *Waitemata Harbour study.* Series of reports, Auckland Harbour Board and Auckland Regional Authority, Auckland.

BIRD, E. C. F., 1971. Mangroves as land-builders. *Vict. Nat.* 88: 189-197.

BRIDGEWATER, P., 1974. Artificial key to saltmarsh plants in temperate Australia. *Operculum* 4: 16-26.

BUTCHER, A. D., 1970. Conservation, environment and industrial development, *Victoria's Resources* 12: 20-22.

CANTERFORD, S. & DUCKER, S. C., 1974. The study of heavy metal accumulation in biological materials in Westernport Bay. *Westernport Bay Environmental Study—Technical Newsletter* No. 2, p. 2.

CONNELL, D. W., 1974a. *Water Pollution—Causes and Effects in Australia.* University of Queensland Press, Brisbane, 132 pp.

————, 1974b. A kerosene-like taint in the Sea Mullet, *Mugil cephalus. Aust. J. mar. freshwat. Res.* 25: 7-24.

COWLES, R. P., 1930. A biological study of the offshore waters of Chesapeake Bay. *U.S. Bur. Fish. Bull.* 46: 277-381.

CROXFORD, A. H. and a research and administrative group, 1973. *Environmental Study of Port Phillip Bay,* Melbourne and Metropolitan Board of Works, Fisheries and Wildlife Dept. (Vic.), Port Phillip Authority, Melbourne.

DAY, J. H., 1967. The biology of Knysna Estuary, South Africa. In: *Estuaries* (G. H. Lauff, ed.) *Amer. Assoc. Adv. Sci.* Publ. No. 83, Washington, D.C. pp. 397-407.

ENRIGHT, J., 1973. Mangrove shores in Westernport Bay, *Victoria's Resources* 15: 12-15.

GILMOUR, A. J., 1965. *The Implications of Industrial Development on the Ecology of a Marine Estuary.* Fisheries Contribution No. 20, Fisheries and Wildlife Department, Melbourne. 24 pp.

HARRIS, J. E., ROBINSON, R. B. & COWDELL, R., 1974. Nutrient and other studies. In: *Westernport Bay Environmental Study—Progress Report, July, 1973-January, 1974,* Ministry for Conservation, Melbourne, p. 53-66.

HEALD, E. J. & ODUM, W. E., 1970. The contribution of mangrove swamps to Florida fisheries. *Proc. Gulf and Carib. Fish. Inst.* 22: 130-135.

HOOD, D. W., SHIELS, N. E. & KELLEY, E. J. *Environmental Studies of Port Valdez,* Institute of Marine Science, Occasional Publication No. 3, Fairbanks. 495 pp.

LOYN, R., 1974. Avifauna investigation. In: *Westernport Bay Environmental Study—Progress Report,* July, 1973-January, 1974, Ministry for Conservation, Melbourne. p. 73-81.

MCERLEAN, A. J. & KIRBY, C., 1972. Biota of Chesapeake Bay—Introduction *Chesapeake Science* 13: S4-S7.

————, ———— & WASS, M. L., 1972. *Biota of Chesapeake Bay—Chesapeake Science,* Vol. 13—Supplement.

MCNAE, W., 1966. Mangroves in eastern and southern Australia. *Aust. J. Botany* 14: 67-104.

NORMAN, F. I. & GOTTSCH, M. D., 1969. The Phillip Island colonies of the Tasmanian Mutton Bird with special reference to those on Cape Woolamai. *Emu* 69: 137-144.

ODUM, E. P., 1971. *Fundamentals of Ecology*, 3rd Edn. W. B. Saunders Co., Philadelphia. pp. 52, 73 and 352-361.

——— & DE LA CRUZ, A. A., 1967. Organic detritus in a Georgia saltmarsh—estuarine ecosystem. In: *Estuaries* (G. H. Lauff, ed.) *Amer. Assoc. Adv. Sci.* Publ. No. 83, Washington, D.C. pp. 383-396.

PRITCHARD, D. W., 1967. What is an estuary: Physical viewpoint. *Ibid.* pp. 3-5.

PRUTER, A. T. & ALVERSON, D. L., 1972. *The Columbia River Estuary and adjacent oceanic waters—bioenvironmental studies,* University of Washington, Seattle.

RAGOTZKIE, R. A. & POMEROY, L. R., 1957. Life history of a dinoflagellate bloom. *Limnol. Oceanogr.* 2: 62-69.

REILLY, P. N. & BALMFORD, P., 1969. Penguin study group—first report. *Australian Bird Bander* 7: 75-79.

——— & ———, 1971. Penguin study group—second report. *Ibid.* 9: 8-10.

SHAPIRO, M. A., 1974. The Westernport Bay Environmental Study. *Water Pollution and the Environment Symposium,* University of New South Wales, Sydney.

SMITH, J. B., 1971. *Littoral Survey of Westernport Bay.* Marine Study Group of Victoria—Interim Report, Melbourne.

TEAL, J. M., 1962. Energy flow in the saltmarsh ecosystem of Georgia. *Ecology* 43: 614-624.

WALSH, G. E., 1967. An ecological study of a Hawaiian mangrove swamp. In: *Estuaries* (G. H. Lauff, ed.) *Amer. Assoc. Adv. Sci.* Publ. No. 83, Washington, D.C. pp. 420-431.

WATSON, J. E., 1971. *The Benthic Flora and Fauna of North-West Westernport Bay, Victoria.* Underwater Research Group of Victoria—Preliminary Report, Melbourne.

WARNECKE, R. M., 1968. The fur seal. In: *Wildlife in South-Eastern Australia,* Australian Broadcasting Commission, Sydney.

WHITLEY, G. P., 1932. Great Barrier Reef Expedition, 1928-29: Scientific Reports—Fishes. *Brit. Mus.* (*Nat. Hist.*) 4: 9.

YONGE, C. M., 1940. Great Barrier Reef Expedition, 1928-29: Scientific Reports—The Biology of Reef Building Corals. *Brit. Mus.* (*Nat. Hist.*) 1: 359-391.

Notation Drawings: Banksia and She Oak